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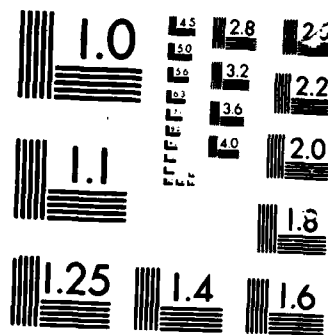
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Welding Science and Technology in Europe:
A Survey and Assessment

Kenneth D. Challenger

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<p>Welding research is organized and coordinated differently within each country, but the International Institute of Welding, serves to coordinate the results on an international scale. The UK, West Germany, and Scandinavia are leading the technological progress in Western Europe, but Eastern Europe places more emphasis on welding research than does the West. In all of Europe the research tends to be applied rather than basic. This report includes a list of key people.</p>			
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WELDING SCIENCE AND TECHNOLOGY IN EUROPE: A SURVEY AND ASSESSMENT

1 INTRODUCTION

The principal organizing body attempting to coordinate welding research worldwide is the International Institute of Welding (IIW). After 38 years, it now has 37 constituent member societies in different countries. The 37 member societies are organized into several different groupings of countries which are in close proximity to each other and share economic objectives. The European Council for Cooperation in Welding (ECCW) exists as one of these groups. The main objective of the ECCW is to provide a forum for the exchange of information in matters of common interest, such as training, professional qualification, and standardization.

This approach of regional groups makes sense in Europe because the funding framework for welding research exists to some extent on an international scale.

Many of the ECCW member countries have centralized welding research institutes and others do not. Industrial laboratories in general appear to focus their development activities on refining existing welding processes, but the results of this work are very seldom made public. The research topics of interest at present to most European countries include mechanized and automated electric arc and resistance welding; solid-phase joining; and high energy density welding (laser, electron, and plasma-beam welding). Most of the current research is focused on steel (including stainless steel) because steel alloys are the principal structural alloys used by the supporting industries (electric power and transportation industries). Fracture resistance of welded structures also receives considerable attention throughout Europe.

Funding for collaborative welding research among members of the European Economic Community (EEC) is available through the European Coal and Steel Community (ECSC), a constituent group with-

in the EEC. Topics proposed for funding by the ECSC are precompetitive in nature and the results of the research available to all EEC member countries.

In the following sections I will attempt to survey the welding research that I am aware of in several European countries. I have probably overlooked some programs and establishments, but I hope to give the reader a general impression of what is being done, the quality of the research, and the quality of the facilities. I start with the UK because the UK's Welding Institute has the largest welding research budget of any single establishment in Europe and is a key organization for welding research in Europe.

2 ACTIVITIES IN INDIVIDUAL COUNTRIES

UK

Welding research in the UK is carried out in a centralized welding institute, private industry, universities and government laboratories. The funding split, as estimated by Dr. Richard Dolby, Director of Research, The Welding Institute, is as follows:

<u>Institute</u>	<u>Annual Research Budget</u>
The Welding Inst.	£10.0 million
Industrial Labs.	£5.6 million
Universities	£1.9 million
Government Labs.	£4.5 million
Total	£22.0 million (~\$33 million)

The Welding Institute. I reviewed the activities of the Welding Institute (TWI) in ESN 39-6:255-261 (1985). TWI serves as the UK center for professional qualification, practical training and education, research, and advisory support to the UK industries involved with fusion welding and other joining processes. The support for TWI comes from membership fees from participating government agencies and industrial firms worldwide. (The US Navy is one of over 100 members from the US whose membership was transferred to the Edison Welding Institute, Columbus, Ohio, last year.)

The research at TWI is high quality and most of it germane to the US Navy. The research is somewhat applied in nature, but nevertheless it is the most fundamental research on welding performed in Western Europe.

I believe TWI is the originator of Group Sponsored Projects in Europe. These are research projects conceived by TWI and then "sold" to any interested industrial firm or government agency. The results are only available to these sponsors. This type of research funding is becoming increasingly popular in France and West Germany at present.

The research projects at TWI of interest to the US Navy are as follows:

- Arc welding--mechanized pulsed gas metal arc welding (GMAW); automatic resistance welding for Al alloys; plasma keyhole welding for pipe; synergic GMAW; hot-wire and powder-metal submerged arc welding (SAW); narrow gap SAW; flux-cored wire GMAW for C-Mn steels; and the cause for variable weldability in steels.
- Fatigue and Fracture--application of CTOD and the J-integral to short cracks; wide-plate test correlations with laboratory test specimen results; dynamic crack initiation and arrest; effect of prior overload; seawater effects on fatigue; random-loaded simulated fatigue testing of structural joints and a computerized fatigue database.
- High energy density welding--vacuum and nonvacuum electron beam welding; high-speed magnetically impelled arc fusion welding; and laser beam-spinning techniques for welding.
- Materials--TWI has one of the most respected materials research teams in Europe studying welding. They are studying variable penetration phenomena; effects of deoxidation practice on weldability and hydrogen assisted cracking in steels; the role of inclusions in determining weld-metal microstructure; development of filler metals for high-speed welding; surface coating for liquid-phase joining

and solid-phase joining; and hypersonic metal spraying.

These items cover all of the research activities at TWI that are germane to the US Navy's interests. All of the research is of high quality, but about half of the projects are group funded, and thus the results are available only to the respective sponsors of the research.

British Steel. The only other welding research program in the UK that I have surveyed is carried out at British Steel's Sheffield Research Laboratories (ESN 38-11:583-585 [1984]). Unfortunately, British Steel is having financial problems to the extent that most of its "research" is really quality control. One exception is the work of Dr. G. Thewlis on the effect of the deoxidation practice on steel weld-metal microstructure. This is a very small effort, but worth following because Thewlis is performing some very careful quantitative metallography on weld microstructures in order to determine the effects of Ca, Ti, Al, Si, and B on the resulting weld microstructure.

Cranfield Institute of Technology. I do not know the details of the research at Cranfield, but I know that the work of Professor Apps is well respected in the UK and that Cranfield is the only educational institution in the UK that offers a degree in welding engineering.

Central Electricity Generating Board. The CEBG is performing research on the welding of ferritic steels (Central Research Laboratory, Leatherhead), stainless steels (Berkeley Nuclear Laboratories) and transition metal joints, stainless to ferritic steel (Marchwood Research Laboratories).

Again, I am not familiar with the details, but their work is well respected. CEBG, Leatherhead, developed the weld procedures to prevent under-bead cracking of the stainless steel weld overlap on ferritic steel nuclear pressure vessels.

The CEBG is one of the leading institutions in the UK that is supporting metallurgical research.

West Germany

Welding research in West Germany is decentralized; thus, official figures concerning welding research funding are not available. The German Welding Society (DVS) is a technical-scientific organization responsible for welding education and welder qualification. The Welding and Cutting Research Association is the organization within the DVS responsible for coordinating all cooperative research activities in West Germany. Ten committees and six working groups with 15 to 20 members each have the responsibility for the preparation and direction of welding research programs, dissemination of the results, application of the results, and representation from industry to government on matters concerning welding research. The members of these committees come from the 100 or so different research institutes (public, government, industry, and academic) connected in some way to welding research.

The Research Association receives about DM6 million (\$2.6 million) from the government each year which it transfers as a 50-percent contribution to the various research institutes for specific research. The remaining 50 percent is generally provided by West German industry. Thus the total funding for cooperative research in West Germany is about DM12 million (\$5.3 million). Funding is, however, not restricted to public sponsorship, and thus it is difficult to estimate precisely the total amount of funding for welding research. Dr. H. Sossenheimer, Director of the DVS, indicated to me that in his opinion between DM40 million and DM50 million are provided by government sources and matching funds are provided by industry. Thus, between DM80 million and DM100 million (\$34.8 million to \$44 million) are spent on welding technology development in West Germany per year.

Every metals research institute that I visited (six in total) in West Germany had some interest in joining technology. The focus of their research varied: developing new welding processes (Professor F. Eichhorn, Aachen Univer-

sity, [ESN 39-4:149-152 (1985)]), underwater welding and weldability (Professor H. Hoffmeister, Hochschule der Bundeswehr, Hamburg), fracture resistance of welds (Professor W. Dahl, EHW and MPA Institute [ESN 39-4:152-156 (1985)]), hydrogen measurement (Dr. H. Meisel, Technical University of Munich), and adaptive control development (Professor P. Drews, Aachen University [ESN 39-4:149-??? (1985)]). Many industrial laboratories are also very active in welding research (ESN 40-2:55-58 [1986]); a large effort to develop mathematical models to predict the postweld microstructure and its hardness and resistance to hydrogen assisted cracking is one point of focus in the industrial laboratories.

In my opinion, there are two key people in the welding research community in West Germany. These are Professors Eichhorn, Aachen University, and H. Hoffmeister, Hochschule der Bundeswehr, Hamburg. They are both very active in the International Institute of Welding and both are very talented and dynamic individuals whose opinions are carefully considered by everyone in Europe who is interested in welding. Any US Navy engineer/scientist with an interest in welding who travels to Europe should make it a point to visit these two men at their laboratories.

France

I am afraid that my information on the welding research activities in France is quite limited. As reported in ESN 40-5:162-165 (1986), I visited the Institut de Soudre, IS, (the French Welding Institute) in Paris (metallurgy and process development) and Metz (fracture and nondestructive testing). As usual with my (and my colleagues) travels in France, language is more of a problem there than anywhere else in Europe (East or West). I am not aware of any welding research other than that performed by the IS, although I am sure that there are large programs elsewhere, certainly at the nuclear research laboratories at Saclay.

All that I can report at present, however, is that IS performs mostly applied research because the support for most of the research at IS comes from French industries and that this research is very important to the French industries. The concept of group sponsorship (like that used by the Welding Institute, UK) is gaining in popularity in France.

The IS spends about 16 percent of its annual budget of FF142 million (~\$20 million) on research. Its main activities are consulting and training. The research is, in my opinion, not very imaginative and certainly not par with that taking place in the UK and West Germany. A recent summary report written by M. Dadian (*ESN* 40-5:162-165 [1986]) is an exception to this statement. He has prepared an excellent summary of how metallurgical research at IS on the subject of weld solidification has benefited the broad subject of physical metallurgy in general. It is worthwhile reading (in French) for anyone interested in physical metallurgy.

One development occurring at the Metz site of the IS that is worth following is their installation of electron beam and laser beam welding equipment. The facility will be the largest of its kind in France, and initially it will be used to demonstrate the capabilities of these welding techniques to interested French industries. This project is completely funded by the French government.

Other Western European Countries

Most of the welding research in Western Europe, excluding that in Scandinavia (described in ONRL report R-2-86), takes place in either the UK, West Germany, or France. Thus, by following the developments in these three countries one will stay abreast of practically all welding research in Western Europe. The activities in some of the other Western European countries are briefly described below.

Belgium

L. Dhooze, Belgian Welding Institute in the Institute Soete, University

of Gent, manages the research activities. Overall, research at the Institute Soete is very progressive (*ESN* 39-8:375-380 [1985]). The welding research is no exception. Quite standard facilities and research projects exist on weldability and fracture mechanics, but some exceptionally good work on nondestructive stress and strain measuring techniques (Dr. P. Boone) is being carried out. Most of the research is germane to US Navy needs and, even though the research activity is small, it is worth following. Most of the research has been supported by the offshore oil and gas industries; the current decline in the price of oil may take its toll in the welding research activities here and throughout Europe.

The Netherlands

I have not visited any of the welding research establishments in the Netherlands (except Shell Laboratories, where I learned of research that Shell supports in Europe, but not what they are doing themselves). However, G.H.G. Vaessen from the Netherlands Institute for Welding (NIL), The Hague, has summarized the activities for me, and Dr. A. Wells (The Welding Institute, UK) summarized the activities in the Netherlands in the paper "Welding Research in the European Community Countries," presented at the International Congress on Welding Research held in Boston in July 1984. According to these two sources, there are about 20 welding research projects that are coordinated by NIL. These projects are funded by industry and government (Ministry for Economic Affairs) on a 50-50 basis. The research is actually performed by the Netherlands Organization for Applied Scientific Research (TNO--primarily Apeldoorn) and the Technical University of Delft. The total funding for this research is about g2.25 million (~\$900,000) per year. The research topics currently under investigation are, in decreasing priority to NIL: residual life of welded components operating at elevated temperature, fracture mechanics of welds, nondestructive testing of welds, weld repair

methods, improvement of manual metal arc welding of steel, high-temperature brazing, and welding of thick offshore structures.

Italy

The Italian Welding Institute, U. Girardi, Director, is the central coordinating and research organization for welding research in Italy. In reality, consulting with industry is the major activity of this Institute and only a very small research effort exists. The research that is done only addresses immediate problems in the field.

I am not sure, but I feel that most of the good research on welding is occurring in the industrial laboratories such as those at FIAT (Turin), CISE (Milan), and Central Steel Research Center (CSM), Rome. These laboratories represent, respectively, the automotive, electric power, and steel industries. FIAT, in particular, is performing some excellent research on the use of laser-beams in metal processing for the automotive industry, (ESN 39-1:16-19 [1985]) and CISE is one of the leading establishments in Europe for the development of laser power sources--several of the CISE lasers are used commercially in the Italian automotive industry (ESN 39-1:16-19 [1985]).

Eastern Europe

Welding research is a major program in the Eastern European countries. In fact, the Eastern countries seem to focus more on topics of interest to the heavy industries (coal, steel, power generation, and construction) than do their western counterparts (ESN 38-12:619-620 [1984]). Dr. B.F. Paton, Director of the Paton Electric Welding Institute, Kiev, USSR, summarizes the state of the art in welding in the communist bloc countries in his keynote paper "State of the Art and Prospects of Welding Engineering Techniques in the CMEA Countries," at the International Congress on Welding Research, Boston, July 1984.

I will present the highlights of his paper in the following paragraphs.

The welding industry is rapidly growing in the CMEA countries. This growth is supported by research from the Bulgarian Welding Institute of Technology, Sofia; The Machine Industry's Institute of Technology, Budapest, Hungary; Central Institute of Welding, Halle, East Germany; Welding Institute, Gliwice, Poland; Welding and Material Testing Institute, Timishoava, Rumania; E.O. Paton Electric Welding Institute, Kiev, USSR; and the Czechoslovakian Welding Research Institute, Bratislava. This research is coordinated by a Welding Coordination Center for the CMEA Countries; each of the above welding institutes participates in this center, as do industrial and design organizations.

Dr. Paton indicated that the CMEA-country scientists contributed 55 percent of papers published in the open literature on the fundamental and theoretical aspects of welding. I have no way to verify this, but my experience indicates that the CMEA countries are performing excellent basic research on welding--much more fundamental than that of their western counterparts.

Improvement of the reliability and efficiency of fabrication are the primary goals of the welding research. The major factor in improving reliability is the reduction in the probabilities of brittle failures and fatigue failures. Cold cracking (hydrogen assisted cracking) is viewed as a major problem area for the steel construction industries.

Compressive residual stresses are induced by explosive and ultrasonic impact (developed in the USSR) to welded structures in order to enhance the resistance to fatigue failures.

Other topics of focus for welding research in the CMEA countries, as described by Paton, are:

- Weldability of high-strength steels
- Joining polymeric materials
- Nondestructive testing methods
- Shielding gas development
- Effect of alloying elements on arc stability
- Flux-cored wire welding

- Narrow-gap welding
- Weld solidification
- Electroslog welding
- Flash butt welding (sewer pipe welder)
- Mechanization and automation
- Welding machines (power sources and process control)
- Continuous laser welding
- Electron beam welding
- Friction welding
- Coating techniques
- Underwater welding

The above topics essentially cover all possible aspects of welding development. I have no idea of the amount of funding devoted to each topic nor any means to measure the emphasis placed on each topic. I did, however, have the pleasure to spend one day at the Czechoslovakian Welding Research Institute (CWRI).

My impressions from this visit are discussed in detail in ESN 39-12:561-565 (1985), but suffice it to say that the magnitude of the research and development activity at CWRI is very impressive. I believe that only one welding institute in the world is larger; that is the Paton Institute in Kiev. CWRI has an annual budget of about KCS70 million (~\$7 million) and it turns over a profit of about KCS20 million from the sale of welding consumables and equipment. It has been growing since its conception in 1946, and at present employs about 850 people (200 with university degrees).

My host, Academician Ivan Hrivnak, is very active in the International Institute of Welding (IIW) and, even with his rather large administrative duties at CWRI and other Academy Institutes (he is the deputy director for six different Academy of Science institutes), he is well informed and knowledgeable about the details of the welding research at CWRI.

The laboratory is well equipped with the same brands of equipment used in the West (very few pieces of research equipment at CWRI were manufactured by a CMEA country). The only area where their

equipment is not up to a par with the West is in microprocessing equipment and its associated software.

Physical metallurgy, weldability of structural materials, welding of highly alloyed steels, test methods and testing of welds, automation of welding, and the development of welding equipment all receive considerable effort at CWRI.

Individually, the researchers are enthusiastic about their work and are better informed on the research that takes place in the West than we are on their research. The research topics that I expect CWRI researchers to focus on in the near future are mathematically modeling the welding process and the resulting mechanical/fracture properties of the weld, computer-aided control of welding, submerged arc welding, and new steel alloys with improved weldability.

As a summary note I want to reiterate that one means for remaining somewhat up to date with the research from CMEA countries (at least with the results that are openly available) is for US researchers to become more active in the International Institute of Welding.

3 CONCLUSIONS AND OBSERVATIONS

Organization and Coordination of Welding Research

Welding research in Europe is organized and coordinated differently in each country, but the IIW serves to coordinate the research on welding on an international scale.

Most European countries have a centralized welding institute where a large fraction of the welding research is carried out. Working Group VII from the IIW recently completed a survey (R.D. Thomas, Jr. and C.B. Shaw, Jr., Analysis of a Welding Survey, IIW Document VII 32-85). Representatives from each member country were asked to estimate which types of organizations carry out welding research and in what proportion (based on expenditures). The results of this survey are combined with my own information in Table 1. Unfortunately I do not have this information for France and West Germany, but I expect that France

Table 1

Types of Organizations Conducting Welding Research
(Percentages of Total Welding Research)

	Centralized Public & Private Welding Research Organization	Industrial Laboratories	Universities	Government Laboratories
Denmark	90	0	5	5
Poland	70	10	20	0
UK	45	25	10	20
Czechoslovakia	40	55	5	0
Canada	20	50	5	25
Italy	20	60	10	10
US	10	30	40	20
Spain	0	90	10	0

Note: Data for France and West Germany not available.

will have a breakdown similar to that of the UK but that West Germany has a larger fraction of welding research in universities and industrial laboratories than does the UK.

It is very interesting to note how the organization of welding research in the US differs from these countries. This may be changing in the US, however, because the Edison Welding Institute, Columbus, Ohio, and the American Welding Institute, Knoxville, Tennessee, were formed last year. These two institutes are in direct competition for funding and each hopes to attract industrial sponsors in a manner similar to the UK's Welding Institute. In fact, the Edison Welding Institute is now connected with the UK Institute, and all of the UK Institute's US members have been transferred to the Edison Institute for a set sum of money (\$750,000 in 1986, I believe). This may leave the Knoxville institute out in the cold, but time will tell if the US can support two welding institutes after years of resisting the formation of only one.

This merge between TWI and Edison was not supported by the American Welding Society (AWS), and, in fact, some duplication of educational and training services now exist between Edison and

AWS. The only thing certain about welding research in the US is that it has severely lacked coordination (on a national level) in the past, and the recent formation of two new welding institutes may have added additional confusion. Time will tell, and in the long run, I believe that the US needs a central research institute. Welding is an interdisciplinary subject requiring the skills of physicists, chemists, metallurgists, and mechanical and electronics engineers. Therefore, a large critical mass of manpower is required to properly address the subject.

Quality of Research

The UK, West Germany, and Scandinavia (see ONRL report R-2-86) are producing the best technological progress in welding in Western Europe, but more emphasis on welding exists in Eastern Europe than in the West. Generally, the research is applied rather than basic in both Eastern and Western Europe. This serves the needs of their industries which strongly support the research, but in my opinion this is somewhat shortsighted. For example, solid-state bonding will become a necessity in order to join the advanced materials that are currently under rapid development

throughout the world. To my knowledge only TWI and a few small university programs are addressing this subject in Europe.

In conclusion, I can safely say that the quality of what is being done is high, but that the research focuses on topics which support heavy industry (oil and gas, transportation, and power generation); thus, joining methods for advanced materials are not adequately addressed. In order to get government funds for research, most European countries require that a cost-sharing industrial partner be found. This is an excellent method to focus the government's funds on topics that will benefit that country's industries, but it tends to encourage applied, rather than fundamental research.

Trends in Research

The major research topic at present in Europe is the mechanization and automation of welding. Consequently, the research is focused on the welding processes most suitable for automation (the gas-shielding and flux-cored wire processes and high energy density techniques) and on the adaptive control systems needed for mechanization. All European countries are developing laser and electron beam welding capabilities.

Key People

The people most informed and influential in European welding research that I have met in my 2 years are as follows:

Dr. A.A. Wells
Dr. R. Dolby
The Welding Institute
Abington Hall
Cambridge CB1 6AL
UK

M. Evrard
M. Dadian
M. Payet
Institut di Soudre
32 Blvd. de la Chapelle
75880 Paris Cedex 18
France

Inq. A. Dhooge
Inq. A.G. Vinckier
Laboratory Soete
University of Gent
Sint-Pictersnieuwstraat 41
9000 Gent
Belgium

Professor F. Eichhorn
Institute für Schweißtechnische
Fertigungsverfahren
Technical University of Hachen
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West Germany

Professor P. Drews
Prozesssteuerung in des
Schweißtechnik
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Professor H. Hoffmeister
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Czechoslovakia

Anyone interested in welding research is advised to try to meet some of these people whenever they visit Europe.

The US Navy has welding requirements that are very similar to those

being addressed by the European welding research community. Many of the Europeans are keen to collaborate, and we have much to gain by doing so.

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